IN-89-CR
53540
P.34

The Ionization Structure of Planetary Nebulae

VIII. NGC 6826

TIMOTHY BARKER[1,2]

Department of Physics and Astronomy

Wheaton College

Received________________________

(NASA-CR-180142) THE IONIZATION STRUCTURE OF PLANETARY NEBULAE. 8: NGC 6826 (Wheaton Coll.) 34 p CSCL 03A

N87-17581

Unclas

G3/89 43731

[1]Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

[2]Guest observer with the International Ultraviolet Explorer satellite, NASA grant NSG 5376. — GODDARD

ABSTRACT

Spectrophotometric observations of emission-line intensities over the spectral range 1400-7200 Å have been made in seven positions in the planetary nebula NGC 6826. The O^{++} electron temperature varies little from 8900 K throughout the nebula; the Balmer continuum electron temperature averages 1500 K higher. The λ4267 C II line intensities imply C^{++} abundances that are systematically higher than those determined from the λ1906, 1909 C III] lines, but because of uncertainties in the intensities of the UV lines relative to the optical ones, this discrepancy is less conclusively demonstrated in NGC 6826 than in other planetaries in this series. Standard equations used to correct for the existence of elements in other than the optically observable ionization stages give results that are consistent and also in approximate agreement with abundances calculated using ultraviolet lines in the few cases where the relevant ultraviolet lines are measurable. The logarithmic abundances (relative to H=12.00) are: He=10.97, O=8.60, N=7.71, Ne=7.96, C=8.53, Ar=6.11, and S=6.77. These results differ somewhat from the recent

study by Aller and Czyzak, in part because their measured electron temperature was somewhat higher. The abundances are quite similar to those in NGC 7662, except that the rather low abundances of He, N, and C suggest that little if any mixing of CNO-processed material into the nebular shell occurred in the progenitor to NGC 6826. The Ar, Ne, and, to some extent, O and S abundances appear to be somewhat low, suggesting that the progenitor to NGC 6826, like that to NGC 7662, may have formed out of somewhat metal-poor material.

I. INTRODUCTION

The previous papers in this series analyzed optical and ultraviolet observations of different positions in the planetary nebulae NGC 6720 (Barker 1980, 1982, 1987; Papers I, II, and VII, respectively), NGC 7009 (Barker 1983; Paper III), NGC 6853 (Barker 1984; Paper IV), NGC 3242 (Barker 1985; Paper V), and NGC 7662 (Barker 1986; Paper VI). The purpose of these studies is to measure optical and UV emission-line intensities in the same nebular positions using similar entrance apertures. Since the ionization frequently changes drastically with position in an extended nebula, this procedure is almost essential in order to make a meaningful comparison between UV and optical measurements. The ultimate goals include the following: (1) to observe elements in more stages of ionization than is possible from optical spectra alone; this provides a check on optical ionization correction procedures, which are still useful for nebulae that are too faint to observe with the International Ultraviolet Explorer (IUE) satellite; (2) by averaging measurements made in different parts of the nebula, to get particularly accurate total abundances so that small differences between nebulae will become apparent; such differences can be sensitive tests of theoretical predictions regarding CNO processing and mixing in the progenitors of planetaries; and (3) to further investigate the discrepancies found in Papers II, III, IV, and V between optical and UV measurements of the abundance of C^{++}; these discrepancies need to be understood before we can have confidence in optical measurements of that important element.

I chose NGC 6826 as the next planetary in this series in part because it has a high surface brightness and so can be observed with reasonable exposure times using the smaller of the two IUE entrance apertures. More importantly, I wanted to measure accurate elemental abundances in the inner part of the nebula because I am currently attempting to determine the abundances in its faint outer envelope for comparison.

II. OBSERVATIONS

a) Optical Observations

The optical observations were made at Kitt Peak National Observatory in 1984 August and 1985 July, using the 2.1m telescope and the intensified image dissector scanner (IIDS). Spectra were obtained through a 3.4" diameter aperture using two grating settings covering the range 3400-5100 Å and 4600-7200 Å with resolutions of about 10 Å (FWHM). The blue spectral region was observed on one night and the red spectral region on as many as three different nights at each of seven different positions in the nebula; offsets with respect to the central star are listed in Table 1.

b) Correction for Interstellar Reddening

The amount of interstellar reddening for each position was measured by comparing the observed and theoretical intensities of the H recombination lines (the "Balmer decrement"). The resulting values of the reddening parameter, c, for each position are listed in the second row of Table 1. The values of c are not significantly different from each other, except for position 7. Although position 7 is the faintest observed, the $H\alpha/H\beta$ intensity ratio agreed well for three different nights. It is possible that this position is somewhat more reddened, either because of internal nebular dust or by more interstellar dust in the line of sight to this part of the nebula. The intensities listed in Table 2 have all been calculated by multiplying the observed intensities by $10^{cf(\lambda)}$; the values of $f(\lambda)$ are also listed in Table 2. Note that there is very good agreement between the observed and theoretical (Brocklehurst 1971) intensities of Hα, Hβ, Hγ, Hδ, H9, and H10 (283, 100, 47, 26, 7.4, and 5.3, respectively) for all five positions.

Two other corrections have been applied to the intensities in Table 2. First, the intensities of the λ3727 [O II] lines have been corrected for blending with other lines as described in Paper III. This correction resulted in the observed intensities being multiplied by factors of 0.78, 0.76, 0.77, 0.84, 0.84, 0.84, and 0.90 for positions 1-7, respectively. Second, a small correction has been applied to all of the line intensities to allow for a recently-discovered slight non-linearity in the IIDS. As measured by De Veny and Massey (1986), the true intensity, T, is related to the measured signal, S, by $S=T^{1.1026}$. Making this correction would not have significantly changed the conclusions of the previous papers in this series. It does, however, result in somewhat smaller reddening parameters, explaining in part the fact that photoelectric measurements of reddening parameters tend to be somewhat smaller than those found using the IIDS (Barker 1978). The correction also gives electron temperatures and He abundances and that are somewhat (roughly 4% on the average) higher than those found previously. Because of the change in electron temperatures, revised elemental abundances average roughly 10% lower than those found previously.

c) Ultraviolet Observations

The ultraviolet observations were made using the small (~3.2" diameter) entrance aperture of the IUE satellite in 1985 February. Table 1 lists the IUE exposure numbers and times. The IUE offsets were made under the assumption that the center of light position measured by the IUE fine error sensor coincides with the central star. As a check, exposures were taken with both the small and large apertures centered on the assumed position of the central star. After allowing for the lower throughput of the small aperture, the observed stellar continuum was about the same for both apertures, and it therefore seems probable that the IUE exposures were made within 1"-2" of the positions given in Table 1. The data were reduced in 1985 June at the IUE Regional Data Analysis Facility at Goddard Space Flight Center using the 1980 May calibration (the same calibration used in the previous papers in this series).

As in the previous papers in this series, putting the UV and optical observations on the same intensity scale is a difficult task because no emission lines could be observed in common. The situation is particularly difficult for NGC 6826 because the lack of He II emission makes it impossible to compare the intensities of the optical and UV He II lines. In addition, the optical observations were not made during periods of consistently photometric weather, and so it is not possible to directly compare absolute flux measurements. Fortunately, G. Jacoby kindly supplied Hβ isophotes based on recent CCD photometry of NGC 6826; Hβ fluxes measured from these isophotes are listed in Table 1. The UV fluxes were then put on the same intensity scale as the optical ones after correcting for the small difference in the areas of the entrance apertures and allowing for the 85% throughput of the small IUE entrance aperture (Harrington _et al._, 1982). This procedure is subject to many uncertainties (in the photometric areas of the apertures, in the correction for interstellar reddening, and in the degree to which conditions were truely photometric when the CCD observations were made), and there is no way to confirm the accuracy of the results. For these reasons, the intensities of the UV lines relative to the optical ones are much more uncertain than in previous papers in this series--a factor of two error is not impossible.

d) Observational Errors

Aside from possible systematic errors discussed above, the UV intensities are judged to be accurate to within a factor of 2 for the faintest lines (less than 20% of $H\beta$), to $\sim$40% for those of intermediate intensity (between 20% and 80% of $H\beta$) and to $\sim$20% for the strongest lines. While these errors may seem high, errors in electron temperatures generally have a greater effect on the accuracy of the abundances determined from collisionally-excited UV lines than do errors in line intensities.

Based on a comparison between the IIDS measurements made on different nights, the intensities of the strongest optical lines are judged to be accurate to $\sim$10%, those weaker than half of $H\beta$ to be accurate to $\sim$20%, and even the faintest lines to be accurate to $\sim$30%.

III. TEMPERATURES, DENSITIES, AND IONIC ABUNDANCES

Calculations of the electron temperature (T_e), electron density (N_e), and ionic abundances in the different positions were made using the same methods and atomic constants as in Paper III. The results for N_e and T_e are summarized in Table 3. The [S II] and [Cl III] lines are all rather faint, and so the values of N_e in the different positions are all somewhat uncertain. The different indicators give generally consistent values of N_e, however, and the densities are in reasonable agreement with those found by other investigators (eg., the value of 2500 cm^{-3} determined by Aller and Czyzak, 1983, for the nebula as a whole). In any event, the calculated ionic abundances are very insensitive to N_e for densities this low.

The ionic abundances are, however, very sensitive to the electron temperature. Unfortunately, the only reliable indication comes from the [O III] lines. The [N II] lines are very faint in NGC 6826 and the T_e's found from them are uncertain even in the two positions where they were measured. The Balmer continuum T_e was measured as explained in Paper V and is also subject to greater uncertainties than the O^{++} T_e because of its extreme sensitivity to errors in c, uncertainties in estimating the continuum, and uncertainties in the instrumental calibration at the Balmer limit. As in Papers V and VI, the T_e measured this way is systematically somewhat higher (by an average of 1500 K in this case) than the O^{++} T_e. As discussed in Paper V, this difference may be due in part to measurement errors, but it is encouraging that it is in very good agreement with the difference of 1460 K calculated from a model of NGC 7662 by Harrington et al. (1982). At least it is clear that there is no evidence that the T_e's measured from the Balmer continuum are lower than the O^{++} T_e's, as has been claimed for some planetary nebulae (see Barker 1979 for a discussion).

The ionic abundances calculated using the values of T_e and N_e given at the bottom of Table 3 are listed in Table 5.

IV. TOTAL ABUNDANCES

Total abundances may be found by simply adding together all the ionic abundances or by using only optically measured ionic abundances and correcting for the presence of elements in optically unobservable stages of ionization. The former procedure would appear to be the more reliable, but unfortunately relatively small errors in T_e will cause large errors in abundances measured from UV lines; this is particularly true for NGC 6826, where the T_e's are quite low. In addition, the intensities of the UV lines relative to the optical ones are particularly uncertain in NGC 6826, as discussed in §IIc. At the very least, however, this method serves as a valuable check on the second procedure, which is commonly used when no UV data are available for a nebula. Both methods were used whenever possible, and the results are summarized in Table 4. The abundances labeled "optical" have been calculated by multiplying the optically measured ionic abundances by the listed values of i_{cf}, the ionization correction factor (the equations used to calculate i_{cf} values are given in Paper III). The abundances labeled "UV + optical" are simple sums of all the ionic abundances.

Except for He, the errors assigned to the abundances are based on the errors estimated for T_e, N_e, and the line intensities. In most cases, the errors in T_e dominate over the other sources.

The average abundances and errors are given in the first row of Table 5. NGC 6826 is one of many planetary nebulae recently studied by Aller and Czyzak (1983; hereafter AC), whose models are based on extensive UV and optical observations made by them and others. Their results are listed in the second row of Table 5 for comparison. Their abundances are somewhat higher on the average, primarily because they measured an electron temperature of 10300K, somewhat higher than the ones found here. In general, the abundance determinations agree fairly well, considering the differences in the methods employed; a detailed discussion is given below.

a) Helium

The three different He I lines agree very well, and the average He^+/H^+ abundance given in Table 5 for each position is an unweighted sum of the three measurements. Since there is no He II emission, the total He abundance is equal to the He^+ abundance in each position. Since there is little [S II] emission in any position, the ionization is high enough so that little if any He is expected to be in the form of He^0. The constancy of the total measured He abundance across the nebula supports this conclusion. The average He abundance (see Table 5) is somewhat lower than that found by AC; this discrepancy is directly traceable to the larger He I line intensities used by them. I believe that the current result, which is based on an average for many different positions that all gave similar values, is more reliable.

b) Oxygen

The λ1661, 1666 O III] lines are unfortunately too faint to measure in all but position 4, and even here the result is very uncertain. Because of this uncertainty, the UV and optical measurements of the O^{++} abundance in position 4 may be said to be consistent, even though they disagree by a factor of almost two. The total measured O abundances agree very well between the different positions. Since the i_{cf}'s are all 1.00, however, this agreement is not evidence in support of the applicability of the ionization correction procedure for O. The average O abundance listed in Table 5 is slightly greater than AC's because of the lower electron temperatures measured in the current study.

c) Nitrogen

The optical abundance agrees quite well with the optical + UV measurement in position 1, the only position where the UV line was strong enough to measure. The optical values for the N abundances are in very good agreement for the different positions, considering the large size of the i_{cf}'s for N. Both of these facts are evidence that the ionization correction procedure for N is valid, and even stronger evidence is provided by the other papers in this series. The average N abundance given in Table 5 is again somewhat higher than AC's, again because of the lower T_e's measured in the current study.

d) Neon

Under the low-ionization conditions of NGC 6826, little if any Ne is expected to be more than doubly ionized, which is consistent with the results listed in Table 4. The total optically-measured Ne abundance is approximately constant and apparently not overestimated in the outer positions (as in Papers I, IV, and VI); in NGC 6826, as in NGC 3242, NGC 7009, and NGC 7662, the ionization is high enough that there is little O^+ and so the different efficiencies of the O and Ne charge transfer reactions are not important (see Paper I and references therein). The average Ne abundance listed in Table 5 agrees well with that determined by AC, but their published value is in error and should actually be 0.4 X 10^{-4} (Aller, 1986 private communication). This value is about half that measured here, again because AC used a higher T_e in their calculations.

e) Carbon

As in NGC 6720, NGC 7009, NGC 6853, NGC 3242, and NGC 7662, the C^{3+} abundance in the inner positions inferred from the λ4267 line is larger than that found using the UV λ1906, 1909 lines. The ratio of the two measurements is 0.94, 2.37, 2.16, 1.40, 1.25, 2.14, and 3.33 for positions 1-7, respectively, so the correlation between decreasing discrepancy and increasing distance from the central star is not apparent in NGC 6826 as it was in the other nebulae. It should be pointed out, however, that, as in NGC 6720 (Paper VII) the relatively good agreemnent in the innermost position may be due to contamination by the stellar continuum there; the λ4267 emission line has an "equivalent width" of only 0.6 Å there, and even a weak absorption line in the spectrum of the central star near this wavelength would cause a large underestimate of the strength of the emission line. In addition, the results for the outer two positions are particularly uncertain because the surface brightness decreases dramatically there, and only a 1"-2" guiding error with the IUE could lead to a factor of two error in the λ1907 flux. As discussed in §IIc, combining the UV and optical intensities is particularly difficult in NGC 6826. At best, then, one can conclude only that there is some evidence for the λ4267 line giving higher C^{++} abundances than the UV line; the magnitude and positional dependence of this discrepancy are not as well determined as in other nebulae in this series.

Considering these uncertainties, the total C abundances (found by summing the UV measurements of the ionic C abundances in each position) are in remarkably good agreement. The average C abundance given in Table 5 is much smaller than AC's value. This discrepancy is due in part to the fact that their C abundance is determined entirely from the λ4267 line, and their measurement of this intensity (which they indicate is uncertain) is about twice the average measured here.

f) Argon

The calculated abundances are in excellent agreement for the five positions, although nearly all the Ar in the nebula is in an observable ionization state and so this agreement does not provide a confirmation of the ionization correction procedure for Ar. The equation $Ar/H = 1.5\ Ar^{++}$ (see Paper I), which is a useful approximation for faint planetaries where only the λ7135 [Ar III] line is observable, gives an average Ar/H ratio of 1.8×10^{-6}, which is close to the actual measured value (see Table 5). The average Ar abundance agrees well with AC's measurement, considering the difference in the T_e used in the abundance calculation.

g) Sulfur

The large scatter in the total measured S abundances is not surprising in view of the faintness of the [S II] and [S III] lines (which are generally considerably less than 1% of Hβ) and the extreme sensitivity of the calculated S^{++} abundance to errors in T_e. Because of these uncertainties, and because of the rather low range of inonization in NGC 6826, it is not an appropriate nebula in which to test the applicability of the ionization correction procedure for S. The average abundance listed in Table 5 is several times the value measured by AC. The explanation again lies partly in their lower adopted T_e, but their lower [S II] and [S III] intensities are also partly responsible. (Interestingly, their i_{cf} of 2.22 is quite close to those found here.) I feel that AC's S abundance, which is almost a factor of 7 less than the average of all the nebulae they studied, is improbably low for a field planetary nebula. Additional evidence for preferring the result of the present study is that it is based on measurements of 7 different positions, some of which having sufficiently low ionization so that most of the S is observable, and all of which give a higher value than measured by AC. As in all the studies in this series, however, it would be valuable to have measurements of the 10.5 μm [S IV] line intensity in the same positions that the optical measurements were made.

h) Comparison of Abundances in Different Objects

In general, the abundances in the objects in Table 5 are similar, but there are some interesting differences. The abundances of He, O, Ne, Ar, and S in NGC 6826 are quite similar to those in both NGC 3242 and NGC 7662. The

He abundances in the three planetaries, which are lower than in any of the other objects listed, imply that there has been little (perhaps no) enhancement of He-rich material in NGC 6826. The abundances of N and C in NGC 6826, however, are lower than those in any of the other planetaries and are in agreement with the values in the sun and H II regions, further supporting the view that little mixing of CNO-processed material occurred in the pre-planetary envelope of NGC 6826. This result is somewhat surprising in view of the existence of an outer halo to NGC 6826, which implies that the inner nebula was formed quite late in the evolution of the star, after there had presumably been sufficient time for mixing to have occurred. The Ne, Ar, and possibly O and S abundances in NGC 6826 are also a bit low, suggesting that NGC 6826, like NGC 3242 and NGC 7662, may have formed out of material that was slightly more metal-poor than did the other objects listed in the table.

V. CONCLUSIONS

In summary, NGC 6826 is another planetary nebula for which total abundances can apparently be accurately determined from optical measurements alone. Although the low electron temperature and lack of He II emission in the nebula make it difficult to estimate abundances from UV lines, there is fairly good agreement between abundances measured optically and those found by combining optical and UV data. As for the other nebulae in this series, however, the optical measurements of the C^{++} are systematically larger than the UV measurements. Although this discrepancy is less well demonstrated in NGC 6826 than in the other nebulae, it still gives further evidence that the λ4267 line intensity is not being interpreted correctly. The abundances in NGC 6826, which differ significantly in most cases from those measured by AC, suggest that NGC 6826 is a planetary nebula that formed initially in a somewhat metal-poor region and has undergone little or no enhancement of its original abundances by mixing with nuclear-processed material.

I am grateful to the IUE and Kitt Peak staffs for their assistance in obtaining the observations, to George Jacoby for supplying the $H\beta$ isophotes, and to Lawrence Aller for sending me his revised abundance measurements.

The use of the Regional Data Analysis Facility at Goddard is also gratefully acknowledged.

TABLE 1

PARAMETERS OF OBSERVED POSITIONS

PARAMETER	POSITION 1	2	3	4	5	6	7
Offset (arcsec)	3W,3N	6N	6S	7W,5N	12N	12S	10W,8N
c	0.16	0.18	0.18	0.14	0.19	0.10	0.28
SWP number	25251	25218	25215	25252	25250	25214	25256
Exposure (min)	100	20	120	80	120	90	58
LWP number	5352	...	5351	5373	5372	5350	5377
Exposure (min)	50	...	50	60	120	90	20
$F(H_\beta)^a$, 2.7" ent.	2.32	2.09	2.09	1.86	0.70	0.70	0.93
$F(\lambda 1907)^a$ IUE small ent.	0.95	0.80	0.71	0.69	0.27	0.22	0.17

[a] Units: 10^{-12} ergs cm^{-2} s^{-1}, uncorrected for interstellar extinction.

TABLE 2

LINE INTENSITIES

			I (λ)						
λ(Å)	ID	f (λ)	Pos.1	Pos.2	Pos.3	Pos.4	Pos.5	Pos.6	Pos.7
1403,1409	O IV]	1.31	13.	...	...	...	...	...	...
1487	N IV]	1.23	...	...	...	...	...	...	...
1548,1550	C IV	1.18	19.	...	...	...	...	...	...
1640	He II	1.14	...	...	...	...	...	...	...
1661,1666	O III]	1.13	...	...	...	3.9	...	...	...
1747	N III]	1.12	1.9	...	...	...	4.1	...	...
1906,1909	C III]	1.23	54.	53.	47.	46.	55.	35.	33.
2326,2328	C II]	1.35	5.3	...	...	...	20.	...	...
2422,2424	[Ne IV]	1.12	...	...	...	...	...	...	...
3133	O III	0.45	...	...	...	...	...	...	30.
3426	[Ne V],O III	0.38	...	...	...	...	...	...	...
3444	O III	0.37	...	...	...	...	...	...	...
3727	[O II]	0.29	15.9[a]	14.5[a]	15.1[a]	25.4[a]	24.3[a]	24.9[a]	77.0[a]
3798	H 10	0.27	4.4	4.7	4.1	4.9	4.6	4.4	4.8
3835	H 9	0.26	7.0	6.8	7.1	7.7	6.3	7.5	7.0
3869	[Ne III]	0.25	54.5	52.0	51.3	48.4	43.9	43.6	44.3

TABLE 2 continued

4069-4076	(blend)	0.21	...	0.5	...	0.4	0.4	0.7	0.7
4102	H δ	0.20	27.1	26.8	26.4	26.6	25.3	26.0	26.1
4267	C II	0.17	0.25	0.62	0.50	0.53	0.51	0.50	0.66
4340	H γ	0.15	47.6	47.3	49.5	47.0	45.9	48.6	47.8
4363	[O III]	0.15	3.94	4.00	4.05	2.98	2.88	3.19	3.26
4471	He I	0.11	4.70	4.61	4.65	4.80	4.54	4.81	4.60
4686	He II	0.05	...	...	...	...	...	...	...
4711	[Ar IV],He I	0.04	1.3	0.9	1.0	0.8	0.7	0.6	0.5
4740	[Ar IV]	0.03	0.49	0.2	0.4	0.2	...	0.3	...
4861	H β	0.00	100.	100.	100.	100.	100.	100.	100.
4959	[O III]	-0.03	265.	263.	270.	242.	227.	244.	234.
5007	[O III]	-0.04	798.	799.	807.	742.	694.	747.	717.
5518	[Cl III]	-0.15	0.27	0.35	...	0.40	0.31	1.49	0.39
5538	[Cl III]	-0.15	0.21	0.32	...	0.33	0.27	1.74	0.51
5755	[N II]	-0.20	...	...	...	...	0.24	...	0.33
5876	He I	-0.22	12.2	12.4	13.0	12.7	12.6	13.8	13.0
6300	[O I]	-0.29	...	...	...	...	...	...	...
6312	[S III]	-0.29	0.45	0.45	0.27	0.72	0.80	0.93	0.74
6563	H α	-0.33	281.	290.	286.	286.	280.	285.	287.
6583	[N II]	-0.34	6.2	6.8	5.9	9.9	10.5	9.5	29.5

TABLE 2 continued

6678	He I	-0.35	3.5	3.7	4.7	3.7	3.6	6.8	3.8
6717	[S II]	-0.36	0.37	0.34	...	0.47	0.64	2.4	1.0
6731	[S II]	-0.36	0.35	0.34	...	0.56	0.82	2.4	1.2
7005	[Ar V]	-0.39	...	...	...	...	...	...	...
7065	He I	-0.40	3.7	3.9	4.2	4.0	2.9	3.5	3.6
7135	[Ar III]	-0.41	9.6	7.2	10.4	11.0	11.0	11.7	10.8

[a]Corrected for blending; see text.

TABLE 3

ELECTRON TEMPERATURES AND DENSITIES

			POSITION						
QUANTITY	ION	RATIO	1	2	3	4	5	6	7
N_e (cm^{-3})	S^+	I(6731)/I(6717)	600	800	...	1400	1700	800	1400
N_e (cm^{-3})	C^{++}	I(5538)/I(5518)	0	5300	...	800	1000	2500	3100
T_e (K)	N^+	I(6583)/I(5755)	...	...	...	...	11600:	...	8900:
T_e (K)	O^{++}	I(5007)/I(4363)	9100	9100	9100	8600	8700	8800	8900
T_e (K)	H^+	I(Bac)/I(H_β)	8400	11400	10600	10400	11100	9900	10900
N_e (adopted)			1000±500	2000±1000	2000±1000	1100±500	1400±1000	1800±1000	2000±1000
T_e (adopted)			9100±500	9100±300	9100±500	8600±500	8700±500	8800±500	8900±500

TABLE 4

IONIC AND TOTAL ABUNDANCES

		POSITION						
λ (Å)	ABUNDANCE	1	2	3	4	5	6	7
4471	He^{+}/H^{+}	0.095	0.093	0.094	0.097	0.091	0.097	0.093
5876	He^{+}/H^{+}	0.088	0.089	0.094	0.091	0.091	0.099	0.094
6678	He^{+}/H^{+}	0.090	0.095	0.121	0.095	0.093	0.175	0.098
Average	He^{+}/H^{+}	0.091	0.092	0.094	0.094	0.092	0.098	0.095
4686	He^{++}/H^{+}	...	...	...	...	...	...	...
	He/H	0.091±0.002	0.092±0.002	0.094±0.000	0.094±0.002	0.092±0.001	0.098±0.001	0.095±0.002
3726,3729	$10^{4}XO^{+}/H^{+}$	0.11	0.11	0.12	0.23	0.22	0.22	0.67
5007	$10^{4}XO^{++}/H^{+}$	3.67	3.66	3.70	4.19	3.75	3.87	3.56
1661,1666	$10^{4}XO^{++}/H^{+}$	...	...	...	7.7:	...	...	...
	i_{cf}	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Optical	$10^{4}XO/H$	3.8±0.8	3.8±0.8	3.8±0.8	4.4±0.9	4.0±0.8	4.1±0.9	4.2±0.9
6583	$10^{4}XN^{+}/H^{+}$	0.015	0.017	0.014	0.028	0.029	0.026	0.077
1747	$10^{4}XN^{++}/H^{+}$	0.66:	...	...	...	...	...	...

TABLE 4 cont.

1487	$10^4 X N^{3+}/H^+$	...	...	...	...	...	...	...
	i_{cf}	34.5	34.5	31.7	19.1	18.2	18.6	6.3
Optical	$10^4 X N/H$	0.52±0.15	0.59±0.16	0.44±0.14	0.53±0.15	0.53±0.15	0.48±0.15	0.49±0.15
UV +Optical	$10^4 X N/H$	0.68:	...	...	...	...	...	...
3869	$10^4 X Ne^{++}/H^+$	0.87	0.83	0.82	1.06	0.86	0.81	0.78
2422	$10^4 X Ne^{3+}/H^+$	...	...	...	...	...	...	...
3426	$10^4 X Ne^{4+}/H^+$	...	...	...	...	...	...	...
	i_{cf}	1.04	1.04	1.03	1.05	1.07	1.06	1.18
Optical	$10^4 X Ne/H$	0.90±0.16	0.86±0.15	0.84±0.15	1.11±0.20	0.92±0.16	0.86±0.15	0.92±0.16
2326,2328	$10^4 X C^+/H^+$	0.16	...	...	...	0.81	...	...
1906,1909	$10^4 X C^{++}/H^+$	2.88	2.83	2.51	4.06	4.37	2.51	2.14
4267	$10^4 X C^{++}/H^+$	2.71	6.71	5.41	5.69	5.48	5.38	7.12
1548,1550	$10^4 X C^{3+}/H$	1.33	...	...	...	...	...	...
UV	$10^4 X C/H$	4.4±2.5	2.8±1.7	2.5±1.5	4.1±2.5	5.2±3.1	2.5±1.5	2.1±1.3
7135	$10^6 X Ar^{++}/H^+$	1.03	0.77	1.11	1.37	1.32	1.37	1.22
4740	$10^6 X Ar^{3+}/H^+$	0.27	0.11	0.22	0.14	...	0.19	...

TABLE 4 cont.

7005	$10^6 X Ar^{4+}/H^+$	...	...	...	...	...	...	...
	i_{cf}	1.01	1.01	1.00	1.01	1.01	1.04	1.02
Optical	$10^6 X Ar/H$	1.3±0.3	0.89±0.2	1.3±0.3	1.5±0.3	1.3±0.3	1.6±0.3	1.2±0.2
6717,6731	$10^6 X S^+/H+$	0.021	0.022	...	0.037	0.050	0.17	0.076
6312	$10^6 X S^{++}/H^+$	1.97	1.95	1.17	4.12	4.32	4.72	3.55
	i_{cf}	2.28	2.28	2.22	1.89	1.86	1.87	1.35
Optical	$10^6 X S/H$	4.5±1.8	4.5±1.8	2.6±1.0	7.9±3.1	8.1±3.2	9.1±3.6	4.9±1.9

TABLE 5

COMPARISON OF ABUNDANCES

Object	He/H	10^4 XO/H	10^4XN/H	10^4XNe/H	10^4XC/H	10^6XAr/H	10^6XS/H	Reference
NGC 6826	0.094±0.001	4.0±0.1	0.51±0.02	0.92±0.03	3.4±0.4	1.3±0.1	5.9±0.9	1
NGC 6826	0.106	2.4	0.32	0.95	18.:	1.1	1.5	2
NGC 3242	0.091	4.4	0.91	1.1	2.6	1.4	3.2	3
NGC 6720	0.110	11.2	2.3	1.8	12.	2.4	10.	4
NGC 6853	0.110	8.4	3.0	2.7	7.6	3.3	5.9	5
NGC 7009	0.117	4.8	1.3	1.5	1.5	2.3	13.	6
NGC 7662	0.094	4.3	1.1	0.9	6.8	1.5	4.2	7
H II regions	0.117	4.0	0.4	1.3	...	...	18.	8
Sun	0.100	7.4	0.9	1.1	4.5	3.7	17.	9,10

REFERENCES - (1) This paper. (2) Aller and Czyzak 1983. (3) Paper V. (4) Barker 1987. (5) Paper IV. (6) Paper III. (7) Paper VI. (8) Hawley 1978. (9) Ross and Aller 1976. (10) Aller and Czyzak 1983.

REFERENCES

Aller, L. H., and Czyzak, S. J. 1983, Ap. J. Suppl., **51**, 211 (AC).

Barker, T. 1978, Ap. J., **219**, 914.

__________. 1979, Ap. J., **227**, 863.

__________. 1980, Ap. J., **240**, 99 (Paper I).

__________. 1982, Ap. J., **253**, 167 (Paper II).

__________. 1983, Ap. J., **267**, 630 (Paper III).

__________. 1984, Ap. J., **284**, 589 (Paper IV).

__________. 1985, Ap. J., **294**, 193 (Paper V).

__________. 1986, Ap. J., **308** (in press; Paper VI).

__________. 1987, Ap. J., (submitted; Paper VII).

Brocklehurst, M. 1971, M.N.R.A.S., **153**, 471.

De Veny, J., and Massey, P. 1986, NOAO Newsletter No. 6, 9.

Hawley, S. A. 1978, Ap. J., **224**, 417.

Harrington, J. P., Seaton, M. J., Adams, S., and Lutz, J.H. 1982, M.N.R.A.S., **199**, 517.

Ross, J. E., and Aller, L. H. 1976, Science, **191**, 1223.

TIMOTHY BARKER: Department of Physics and Astronomy,
Wheaton College, Norton, MA 02766